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Agent-based modelling for flood evacuation as inclusive disaster risk reduction: Pilot participatory action research with 11- and 12-year-old children from a Japanese school

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ABSTRACT

Climate change has increased the prevalence of natural hazard threats like flooding across the world, which has resulted in a heightened risk in already flood-prone communities. As a result, more focus needs to be placed on climate change adaptation such as ensuring effective response (e.g. flood evacuation) to safeguard that livelihoods are protected in worst-case scenarios. This study was a participatory action research (PAR), engaging Japanese school children (aged 11 and 12) in Wakayama prefecture, Japan, in a series of interactive workshops focused on discussing flood evacuation and facilitating exposure to Agent-Based Modelling (ABM), which has potential to facilitate disaster preparedness learning in this context. As current flood evacuation is predominantly informed by topographic and demographic data, there is an exclusion of key impacting variables like social data (e.g. evacuation start times, etc.), and this research sought to include these. Through homework exercises issued to school children, social datasets were collected and included within a computational model of flood evacuation, creating an enhanced ABM-approach. Results illustrated that when comparing the enhanced model to an initial model that did not include social datasets, the addition offers more detailed and accurate insights into flood evacuation behaviour. Also, feedback from the school children that followed the workshops further established that engagement through the use of ABM raised awareness and interest towards their flood evacuation, which is essential to successful DRR. These findings suggest that consideration of variables beyond topography and demographics needs to be taken into account within future ABM in this context, and taking a participatory approach in ABM can have benefits to engage and educate samples affected by disasters. The study will need to be expanded to include the same approach within schools beyond Japan, and include other stakeholders where flooding is an increasing issue, and enlarge social variables used to ensure greater robustness in the modelling.

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1. Introduction

There is scientific consensus that climate change impacts like flooding are becoming more frequent and intense [1]. And such a reality does not discriminate based on continental position or development status, these negative impacts have a universal effect – no nation is immune, though the scale of impact varies depending on geography and other factors [2]. Yet, efforts by the United Nations, non-governmental organisations and individual countries to address climate change have yielded no resolution [3], despite the production of some useful pro-environmental policies and protocols like the UN Framework Convention on Climate Change aimed at limiting global warming to ideally below 1.5 °C above pre-industrial levels, and UN's 2030 Agenda for Sustainable Development integrating climate action into broader global goals like ending poverty and improving health. While it is crucial to continue such efforts, in parallel there is a need to engage in worst case scenario preparation to ensure that there is sufficient climate change adaptation to facilitate an effective response, especially when natural hazards become extreme threats – this is crucial for preventing the loss of human life. The basic premise of DRR is the reduction of disaster risks through systemic review and addressing of causal factors that manifest disasters. It is particularly important in countries that are predisposed geographically to climate change impacts like extreme flooding, for instance Japan, Sri Lanka, Pakistan, and many others. In places like Japan, there is a present pressure to keep improving adaptation processes as the danger of natural hazards is relatively high [4], but outcomes from research in such places are similarly likely to inform best practice across the world, especially in countries like the UK or elsewhere where the risk of flooding is increasing substantially (Environmental Agency, 2023), so there is a shared benefit to investigating adaptation strategies in Japan.

A key approach in climate change adaptation in the context of flooding is flood evacuation, where in simple terms, people move from an area of risk to an area of relative safety [5]. In practice, local councils are required to have and update evacuation plans as part of their emergency planning, which includes using risk assessments and national agency information to inform best practice [6]. There is a need to ensure that these plans are optimal considering the high stakes that dealing with potential extreme natural hazards contains. Current flood evacuation models are predisposed to being based on demographic and topographic data in mapping areas [7] that limits their predictive capacity in terms of accurately understanding human behaviour in emergency situations – there is a high degree of undesirable uncertainty, which carries a high risk in such circumstances.

This research seeks to move beyond only using such data by utilising social datasets (data relating to individual's activities and interactions in their social contexts) within Agent-Based Modelling (ABM). This type of modelling focuses on individual 'agents' as active elements of a system, expressing human behaviour within computer simulations with data inputs acting as multipliers that determine human movements within a given area [8]. Further details on how ABM is used in the study are outlined in the background, methodology and results sections of this paper. Using ABM together with social datasets is novel, enabling the creation of an enhanced model of flood evacuation as opposed to one that only uses basic datasets with no input from the area's resident population. As there is a necessity to improve evacuation efforts, engaging in ABM research within this context provides promise and insight that can help inform future flood evacuation interventions. It should be noted that when discussing modelling in this study, the term tsunami evacuation is used as this reflects the tsunami risk faced by the area the research is based on, but when reflecting more broadly, this study employs the term flood evacuation as a means to be more inclusive of areas where more generally, flooding is the risk (and where tsunamis are not a likely occurrence).

Beyond the novelty of utilising social datasets within ABM, this study also sought to engage in participatory action research (PAR) by utilising children in the construction of the ABM to enable direct knowledge transfer and learning, helping to present complex information in simpler ways that can be more easily understood. And there is a need to include wider stakeholders like children in DRR, as their views may hold critical insights about the specific contexts being observed [9]. Such an approach has not been taken before, meaning that it is the first time that the efficacy of ABM in facilitating learning within this context is being observed. It was deemed important to establish this PAR component to the research, especially with the inclusion of children as there is a substantial body of evidence that expresses the need for early education interventions and their benefits, especially in establishing best practice in emergency situations like flooding, early on, to benefit future DRR objectives and outcomes [10]. Likewise, the background, methodology and results sections delve into deeper detail regarding the use of PAR in this project.

On the basis of the above, this study aimed to answer the following questions.

1. How can agent-based modelling be utilised to respond to the conditions and needs of a local area for effective flood evacuation?
2. How do children gain ownership in DRR action and develop DRR knowledge and skills?
3. Is ABM with PAR an impactful way of engaging local residents to promote DRR awareness?

2. Background

2.1. Flood management & limitations of physical structures

Coastal areas worldwide are increasingly vulnerable to flooding due to sea-level rise, increased storm intensity, and coastal erosion [11,12]. Physical structures like breakwaters, seawalls, and levees are engineered solutions designed to mitigate the risks above. These structures aim to protect shorelines, prevent coastal erosion, and reduce the impact of storm surges and flooding. However, these defences are not foolproof and cannot entirely prevent flooding under all circumstances. Understanding their influence on floodwater behaviour and the limitations they present is crucial for effective disaster risk reduction (DRR) strategies.

Physical structures like breakwaters and seawalls are subject to wear and degradation over time. Their effectiveness can be compromised by material fatigue, poor maintenance, and extreme weather events. Moreover, these structures often fail to adapt to changing conditions, such as rising sea levels and increased storm intensity due to climate change. For example, many seawalls were not designed to cope with the higher water levels and more significant storm surges predicted for the future [13]. The construction of breakwaters and seawalls can significantly alter coastal ecosystems. These structures can disrupt natural sediment transport, leading to beach erosion and changes in coastal habitats. This disruption can have cascading effects on local biodiversity and fisheries. For instance, seawalls can lead to the loss of intertidal zones, which are critical habitats for many marine species [14].

Recent studies have highlighted both the efficacy and the limitations of physical coastal defences. For example, a study by Takabatake et al. [15] examined the effectiveness of coastal forests and dykes in reducing tsunami-related casualties. The study found that while these structures can significantly reduce the impact of flooding, their effectiveness is limited and should be part of a broader, integrated risk management strategy [15]. Breakwaters and seawalls are the most common coastal defence structures. Breakwaters are offshore structures that protect coastlines by breaking the force of incoming waves, thus reducing erosion and preventing flooding. They work by absorbing and dissipating wave energy, creating a calm zone behind them where sediment can accumulate. Seawalls, on the other hand, are vertical or sloped barriers built along the coast. They act as physical barriers to prevent the sea from encroaching onto the land, protecting the hinterland from wave action and storm surges [16]. In Japan, extensive seawalls built following the 2011 Tohoku earthquake and tsunami have been critical in protecting coastal areas. However, they have faced criticism for disrupting natural landscapes and habitats, and their effectiveness is debated, especially under the scenarios of extreme events [17]. In synthesis, it is highly desirable to look beyond physical structures to ensure that effective response is less disruptive, while still being impactful.

2.2. Agent-based modelling

Agent-based modelling (ABM) is a methodology that simulates the behaviours and interactions among numerous agents. Each agent is modelled as a decision-making entity that autonomously determines its actions based on predefined rules [8]. By programming agents to mimic human behaviours, ABM can replicate complex phenomena that occur in human society, such as crowd evacuation in case of natural disasters. Because of its effectiveness, ABM has been extensively utilised to represent evacuation processes in case of various natural disasters (e.g., Ref. [18–21]).

Several studies have also employed ABM to tsunami disaster scenarios. For instance, ABM has been utilised to evaluate current tsunami evacuation procedures in specific coastal areas (e.g., Ref. [22–24]). Additionally, some researchers have employed ABM to assess the effectiveness of various tsunami countermeasures, including elevating seawalls [25,26], implementing early evacuation measures [26–28], increasing the number of tsunami evacuation shelters [29,30] and utilising vehicles for evacuation [31,32].

Despite these applications, considerable assumptions are often made to model the tsunami evacuation behaviour of at-risk individuals in ABM. For instance, evacuation start times of evacuees are typically modelled by using either a constant time (e.g., 5 min after the onset of an earthquake event) (Muhammad et al., 2021; Takabatake et al., 2022) or probabilistic distribution function (e.g., Rayleigh distribution) [22,23,30]. It is also commonly assumed that evacuees would take the shortest path to the nearest refuge from their locations [33,34]. While these simplifications are useful when comparing the effectiveness of different evacuation strategies (as modelling complex behaviours would complicate comparisons) [35], it is crucial to input more detailed representations of intended evacuation behaviours to accurately simulate scenarios that are likely to occur in coastal areas during an earthquake and tsunami. To improve the simulation accuracy of such scenarios, some existing studies have incorporated the results of previous surveys on intended evacuation behaviour into their evacuation simulation model (Katada et al., 2013; [36]). However, to the best of the authors' knowledge, no study has yet collected detailed data on intended evacuation behaviour from residents of a specific coastal area by interactively collaborating with local school children, with the goal of refining the assumptions used during the ABM modelling of evacuation behaviours.

2.3. Community & school engagement for DRR

Community awareness and education are critical components of disaster risk reduction. Effective communication about the limitations of physical structures and the importance of evacuation plans can save lives during extreme flood events. Public education campaigns should focus on informing residents about the risks they face, how to interpret warning systems, and what actions to take during an emergency [37].

Evacuation planning must consider human behaviour, including the tendency for people to underestimate risks or delay evacuation. Best practices in public communication include clear, consistent messaging and the use of multiple channels to reach different audiences. Evacuation plans should be regularly updated and tested through drills and exercises, ensuring that all community members understand the procedures [35].

Recent developments in evacuation planning include the use of technology and social media to disseminate information quickly and efficiently. For example, the use of mobile apps for real-time updates and the integration of geographic information systems (GIS) to map evacuation routes and shelters are becoming increasingly common. Case studies from Japan and the United States of America highlight the importance of involving community members in the planning process to ensure that plans are realistic and culturally appropriate [38].

There is evidence to suggest in DRR research that 'starting early' is an effective pathway for resilient communities ([10]; Luetz and Sultana, 2019; [39]). Children growing up with high disaster awareness is significant in times of climate emergency. Besides, they bring their disaster learning to adults around them, leading to positive changes in communities. The perspective that children and young people do have a stake in society derives from human rights and citizenship scholarship ([40]; Starkey and Osler, 2005).

Existing social systems tend to treat children as subject to protection. The importance of protection is undisputable, but children have agency and capacity to collaborate and make decisions. This pilot study intended to facilitate co-production and co-decision-making processes in DRR education. Furthermore, paying attention to the point that children inspire and influence adults, we consider children as catalysts for the formation of disaster resilience in communities.

One of the effective methodologies to involve children in the production of DRR knowledge is PAR. PAR has proactive social participation and co-production emphases, which provides research with an analytical and operational direction [41]. Originated by emancipatory theorists such as Freire [42] and Fals-Borda [43], PAR is a research methodology that deals with real problems including climate emergency advocating greater justice and transformative values through '*participation*' [44]. PAR considers research participants are 'co-learners and co-producers' of knowledge, and such a proactive or 'thick' form of participation should lead to an '*action*' [45]. '*Research*' thus becomes a cyclical process of reflection and action [46,47]. PAR usually follows the following phases suggested by many PAR researchers including Charnes [48]: initial open-space meeting, the constitution of PAR groups, critical enquiry, action, evaluation, revised action, second evaluation, further revised action and final evaluation. As a pilot study, our research applied PAR's first principle of participants as co-producers' of knowledge to test whether a cyclical process of reflection and action would be possible in a planned future study.

Many 'participatory' DRR projects at school tend to use knowledge-transmission models of learning and teaching deploying pre-designed activities [49,50]. Our goal is to co-generate an activity with children. By doing so, they will build a sense of ownership of the activity, which is critical in sustainable and inclusive DRR.

3. Methodology & results

The methodology and results section of this paper is split into two parts, with one describing the methodology behind the construction of the ABM, the corresponding data that was input into the model, and the outcomes from the modelling process. And the other part, describing the workshops that children took part in and feedback that arose from these.

3.1. Part 1: agent-based modelling

3.1.1. Participants

The participant base for the research consisted entirely of individuals who were residents of Inami town in Wakayama prefecture, representing in variable numbers, each of its component Wards – Usugi, Hikarugawa, Yamaguchi, Age, Tsui, Hama, and Hongo (more about this in part 2). This identity formed a key part of the participation criteria that was enacted by Inami junior high school children who independently surveyed family members and friends (who were all residents). In total 66 individuals were surveyed, 54.5 % were female, while 45.5 % were male. In terms of participant age, 63.6 % were 10–19 years, 7.6 % were 30–39 years, 19.7 % were 40–49 years, 6.1 % were 50–59 years, 1.5 % were 60–69 years, and 1.5 % were undisclosed ages. No other demographic data was collected

Fig. 1. Geographical position of Inami town in Wakayama prefecture and Japan. Sourced from Google Maps.

about the participants in this study, as the focus of this research mainly considered participant responses, and not the role of their demographic characteristics.

3.1.2. Study location – Inami Town in wakayama prefecture, Japan

Inami town was chosen as an area of research focus for several reasons. Mainly, it is an area of high flood risk with significant historical flooding especially due to its exposed coastline and a pronounced orographic gradient moving inland from the coastline (see Fig. 1 for location visual). These characteristics enshrine a state of vulnerability that requires regular review, especially as there is an aging population that mandates reflection on the social roles and responsibilities of inhabitants whose age influences capacity for DRR engagement significantly. Beyond this, as there are challenges in obtaining gatekeeper access to schools in Japan, this area was chosen due to pre-existing research links with Inami town council, and Inami elementary school, which facilitated meaningful exchanges in the organisational management of the research. Furthermore, social data from this area has not been used in ABM before (especially as using social data in this context and manner is a new approach), so this serves as a novel case study example, which provides insight into the applicability of this kind of modelling within this specific context.

3.1.3. Data collection & analysis

This project took the form of PAR wherein Japanese junior high school children between the ages of 11 and 12, undertook a series of workshops (2 in November 2023 and 1 in January 2024) explaining ABM and discussing flood evacuation efficacy (more information about this is in part 2 of the methodology and results). This formed a key role in knowledge building and personal reflection about behaviour during emergency situations. To facilitate direct involvement in the research, while also enhancing the school curriculum, the children were issued homework, that required them to survey Inami town residents to collect social data like evacuation times as well as other useful information relating to flood evacuation. This social data represented the input data for the ABM. Once datasets were gathered about evacuation behaviour based on the survey responses that the children collected as part of their homework exercise, this data was embedded within the ABM computational simulations – in the enhanced model produced, the evacuation times were focused on. By using data such as the expressed evacuation starting times of individuals as opposed to assumed starting times, the ABM reflected these differences in the changing colours of dots that represented agents – the varying colours were based on

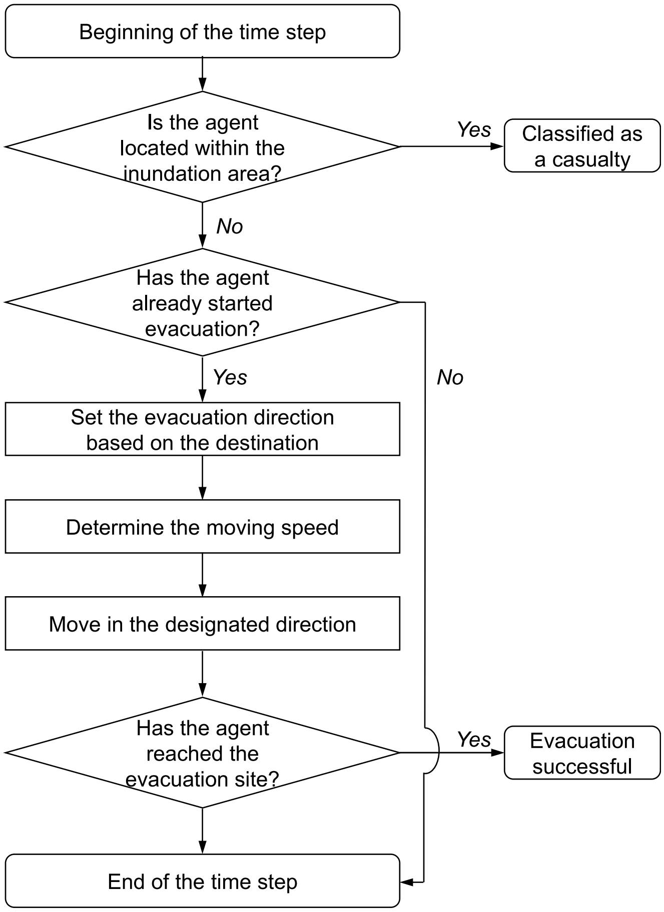

Fig. 2. Flowchart outlining the actions each agent takes at each time step in the ABM simulations.

whether 'agents' were still, in motion or caught by floodwater, etc.

3.1.4. Setup of ABM

The ABM simulation model employed in this study was developed by the authors, using artisoc4 (Kozo Keikaku Engineering Inc., 2020), which is a well-known agent-based modelling platform. Fig. 2 shows a flowchart outlining the actions each agent takes at each 1 s time step. Here, each agent begins these actions at the occurrence of an earthquake (time = 0 s) and continues until the significant inundation phase is nearly complete (time = 3600 s). At the beginning of each time step, an agent is defined to first check whether it is located within the inundated area at that specific time. If the agent is within the inundation area at that time step, it is classified as a casualty, and its status is updated accordingly. Specifically, these agents are set to no longer perform actions in subsequent time steps, and their colour in the simulation visualization is changed to black to indicate that they have become casualties. The inundation extent at each time step is calculated using a tsunami propagation and inundation model previously developed and validated by the authors (Takabatake et al., 2019; [51]). If an agent is not located in the inundated area at this time step, the agent then determines whether it has already initiated the evacuation process. If evacuation has been initiated, the agent sets the movement direction based on its designated destination. For instance, if the agent's goal is to reach the closest evacuation site along the shortest path, it sets the movement direction accordingly and prepares to proceed along that path. Subsequently, the agent computes its speed of the movement, which is adjusted according to the type of roads (e.g., narrow roads, slopes, and stairs). After calculating this speed, the agent advances to the determined destination towards its the designated direction. If the agent reaches an evacuation destination during this time step, it is classified as having evacuated successfully and is excluded from the subsequent simulation steps. However, if the agent does not reach its destination, it will continue its evacuation efforts in the following time steps (see Fig. 3).

In this study, three simulations were performed under different assumptions. Specifically, the assumptions regarding the evacuation start times, evacuation paths, and evacuation speeds were varied across the three simulations. A summary of these assumptions is provided in Table 1. In the first simulation, all evacuees (i.e., the agents) were assumed to begin their evacuation 15 min after the onset of the earthquake. Note that this assumption is based on observations from the 2011 Tohoku Tsunami, where 50 % of the affected population reportedly initiated evacuation within around 15 min (Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2013). Additionally, all evacuees were modelled to move to the closest evacuation site via the shortest path at a constant speed of 1.0 m/s [52] (see Table 2).

In the second simulation, only the evacuation start times were adjusted based on the data collected from the students. In other words, in this simulation, the evacuation paths and moving speeds were identical to those used in the first simulation, and it was assumed that 76.5 % of the evacuees would begin evacuation 50 s after the earthquake, which corresponds to the time when ground shaking subsides, 15.7 % would begin 3 min after the earthquake, which coincides with the issuance of tsunami warnings, and 7.8 % would evacuate upon visually observing the tsunami. These percentages represent the average evacuation start times across Inami Town as a whole, which were derived from survey results collected by the students.

The third simulation applied different evacuation conditions to each district (i.e., Yamaguchi, Aga, Usugi, Hama, and Hongo) in Inami Town using district-specific data obtained from the survey. Here, the evacuation start times were refined based on the percentages obtained from each district. Additionally, the evacuation paths were varied according to the survey responses from each district. For example, evacuees who indicated they would move to the closest evacuation site were modelled accordingly, while those who specified a particular destination in the survey were routed to that location. Evacuees who were uncertain about their destination were modelled to follow other evacuees in front of them, or, in the absence of others, to move randomly within the area. The moving speeds in the third simulation were determined based on road type data collected from the students. On general roads, the evacuees were assumed to move at 1.0 m/s (identical to the first and second simulations). However, on crowded narrow roads, the moving speed was reduced to a minimum of .2 m/s (following [33]). Furthermore, evacuees moving on slopes were assumed to move at .4 m/s (following Ministry of Land, Infrastructure, Transport and Tourism, 2013), and evacuees on stairs or other challenging paths were assumed to move at .2 m/s [52]. In addition, the students reported that bridges could potentially be impassable due to the earthquake;

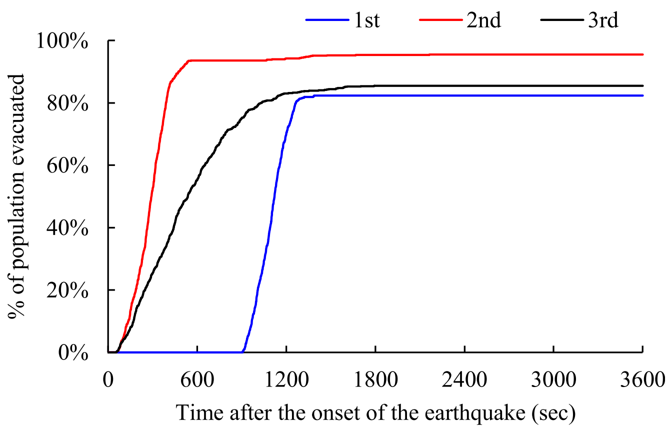

Fig. 3. Percentages of evacuees who reached evacuation sites with respect to time for each simulation case.

Table 1
Assumptions in each simulation.

Assumptions	First simulation	Second simulation	Third simulation
Evacuation start time	All evacuees were assumed to begin evacuation 15 min after the earthquake.	Evacuees were assumed to begin evacuation based on three assumptions, using the overall average for Inami Town.	Evacuees were assumed to begin evacuation based on three assumptions, using district-specific averages.
Evacuation paths	All evacuees were assumed to move to the closest evacuation site along the shortest path.	Identical to the first simulation.	Evacuees were assumed to move to the closest evacuation site, a specified destination, or follow other evacuees, based on district-specific survey responses.
Evacuation speed	Evacuees were assumed to move at a uniform speed of 1.0 m/s on all road types.	Identical to the first simulation.	Evacuees were assumed to move at varying speeds depending on the road type and conditions, such as slopes, stairs, and narrow roads.

Table 2
Distribution of pupils by district.

District	Frequency	Percentage (%)
Hama	7	21.2
Hongo	2	6.1
Age	5	15.2
Usugi	6	18.2
Hikarugawa	3	9.1
Tsui	2	6.1
Yamaguchi	6	18.2
Other	2	6.1
Total	33	100

thus, bridges were modelled as inaccessible, and the evacuees were routed to avoid the bridges in the third simulation.

3.1.5. Results

Fig. 2 presents the percentages of evacuees who reached evacuation sites over time for each simulation case. In the first simulation, as all evacuees were assumed to begin evacuation 900 s after the earthquake, no evacuees finished evacuation before this point. Nevertheless, as they evacuated along the shortest path to the closest evacuation sites at a constant speed of 1.0 m/s, approximately 80 % of the evacuees reached the evacuation sites within 360 s after beginning evacuation, and the remaining evacuees were caught by the tsunami. In the second simulation, 92.2 % of the evacuees initiated evacuation within 300 s after the earthquake. Consequently, all these evacuees completed evacuation before the tsunami arrival (approximately 1200 s after the earthquake), and only those who started evacuation upon observing the tsunami were caught by it. In the third simulation, while the assumptions for evacuation start times were like those in the second simulation (though assigned based on district-specific data), a considerable number of the evacuees did not go to the closest evacuation site and instead followed other evacuation routes with slower moving speeds. As a result, the percentage of the evacuees who completed evacuation before the tsunami arrival was significantly lower compared to the second simulation, and ultimately, the percentage of the evacuees who successfully evacuated was similar to that in the first simulation.

Figs. 4–6 display the snapshots of the ABM simulation for the first, second, and third simulation cases, respectively. The selected timestamps (e.g., 60 s, 180 s … 2300 s) were chosen to highlight key differences among the three simulation scenarios, as these time steps effectively illustrate the varying evacuation behaviors and outcomes under different assumptions. In the first simulation case, all evacuees were modelled to start evacuation 15 min (900 s) after the earthquake. Therefore, agents did not begin to evacuate until 900 s, as indicated by the yellow colour (Fig. 4a and b), and many agents were still evacuating at 1000 s after the earthquake (Fig. 4c). As the tsunami wave inundated the study area approximately 1100 s after the earthquake, evacuees initially located near the coast were caught by the tsunami. Consequently, their markers changed to black, as depicted in Fig. 4d–f. The estimated number of affected people in the first simulation case was 270. It should be noted that Fig. 4d and e shows fewer black dots than the estimated number of affected individuals; this is due to the dots representing each agent being made larger in the present simulations (to improve readability), which resulted in many dots overlapping each other.

In the second simulation case, the evacuees were modelled to start evacuating at different times. Specifically, the authors assumed that 76.5 % of the evacuees would start evacuating 50 s after the earthquake, 15.7 % would begin 3 min after the earthquake, and the remining 7.8 % would do so upon seeing a tsunami. This earlier initiation of evacuation, compared to the first simulation case, is evident in Fig. 5a and b, where a significantly larger number of the evacuees already started evacuating. As a result of the earlier evacuation, most of the evacuees successfully reached their destinations by 1000 s post-earthquake, rendering them no longer visible in the simulation, as shown in Fig. 5c. However, most evacuees who were modelled to begin evacuation upon seeing the tsunami, indicated by yellow dots in Fig. 5c, failed to evacuate in time and were subsequently caught by the tsunami, as depicted in Fig. 5d–f. The estimated number of affected people in the second simulation case was 69, markedly fewer than the first simulation case. This reduction in the number of affected people highlights the importance of early evacuation, either upon feeling the earthquake or receiving a tsunami warning, as a key factor in saving lives.

In the third simulation case, the starting times for evacuation were adjusted based on the responses from each district (Fig. 6a)

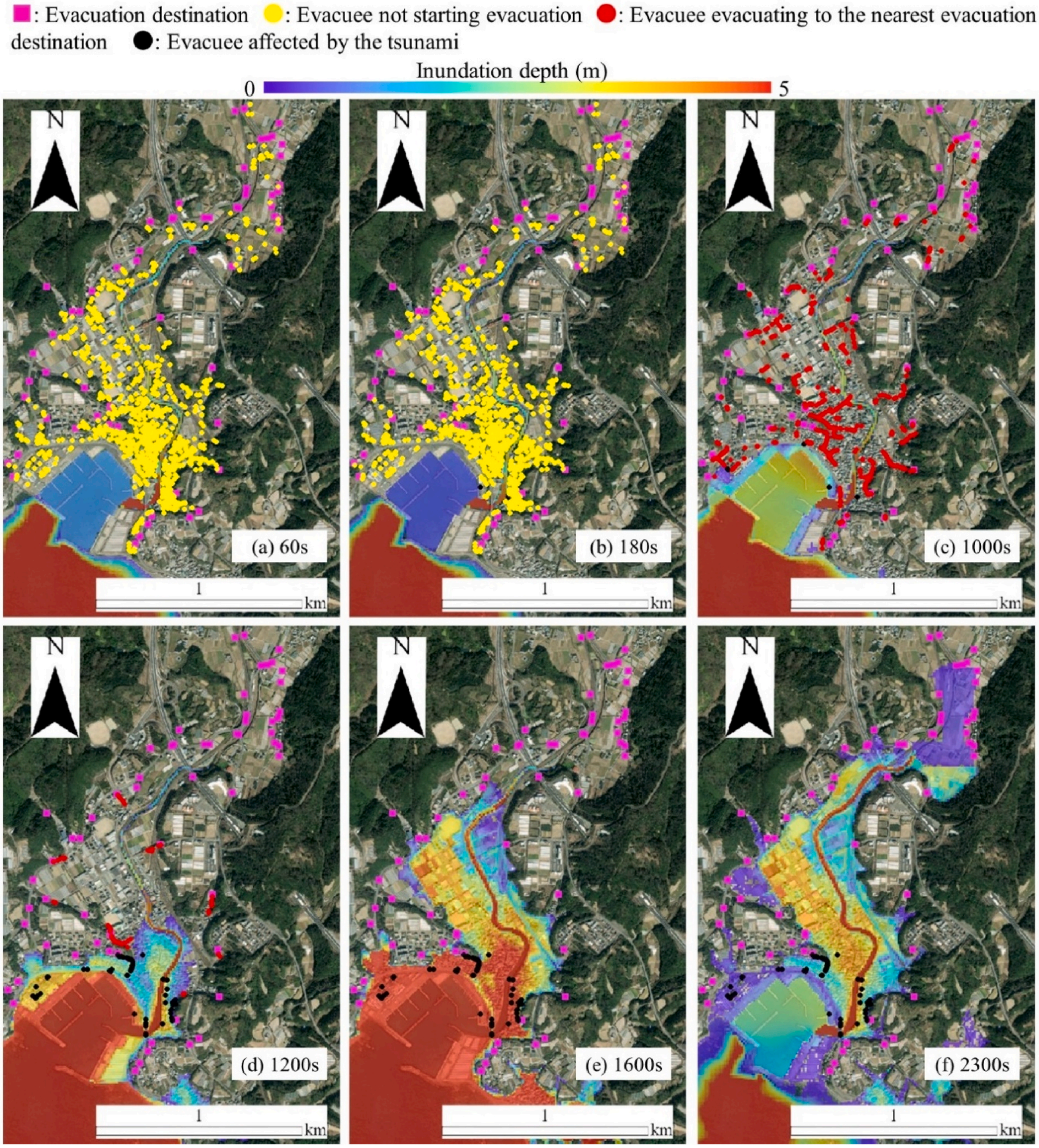

Fig. 4. Snapshots from the first simulation case at (a) 60 s, (b) 180 s, (c) 1000 s, (d) 1200 s, (e) 1600 s, and (f) 2300 s following the occurrence of the earthquake.

rather than applying the overall survey percentages used in the second simulation case. For instance, since all respondents in the Yamaguchi and Hongo districts indicated that they would start evacuating immediately after feeling ground shaking or hearing a tsunami warning, evacuees in these districts began their evacuation within 180 s of the earthquake, as evidenced by the absence of yellow dots in these districts in Fig. 6a and b. The third simulation case also modelled evacuees who would evacuate to non-nearest evacuation destinations (shown in blue) or follow other evacuees (shown in green). Additionally, the moving speeds were adjusted based on the road types. As a result, although the same number of agents began evacuating within 180 s in both the second and third simulation cases, agents in the third case took longer to reach their destinations, evident from the higher number of evacuees still moving at 1000 s (compare Figs. 5c and 6c). This delay resulted in a higher number of affected people than the second simulation case, as indicated by the significant presence of the black dots in Fig. 6d–f. The estimated number of affected individuals in this case was 222.

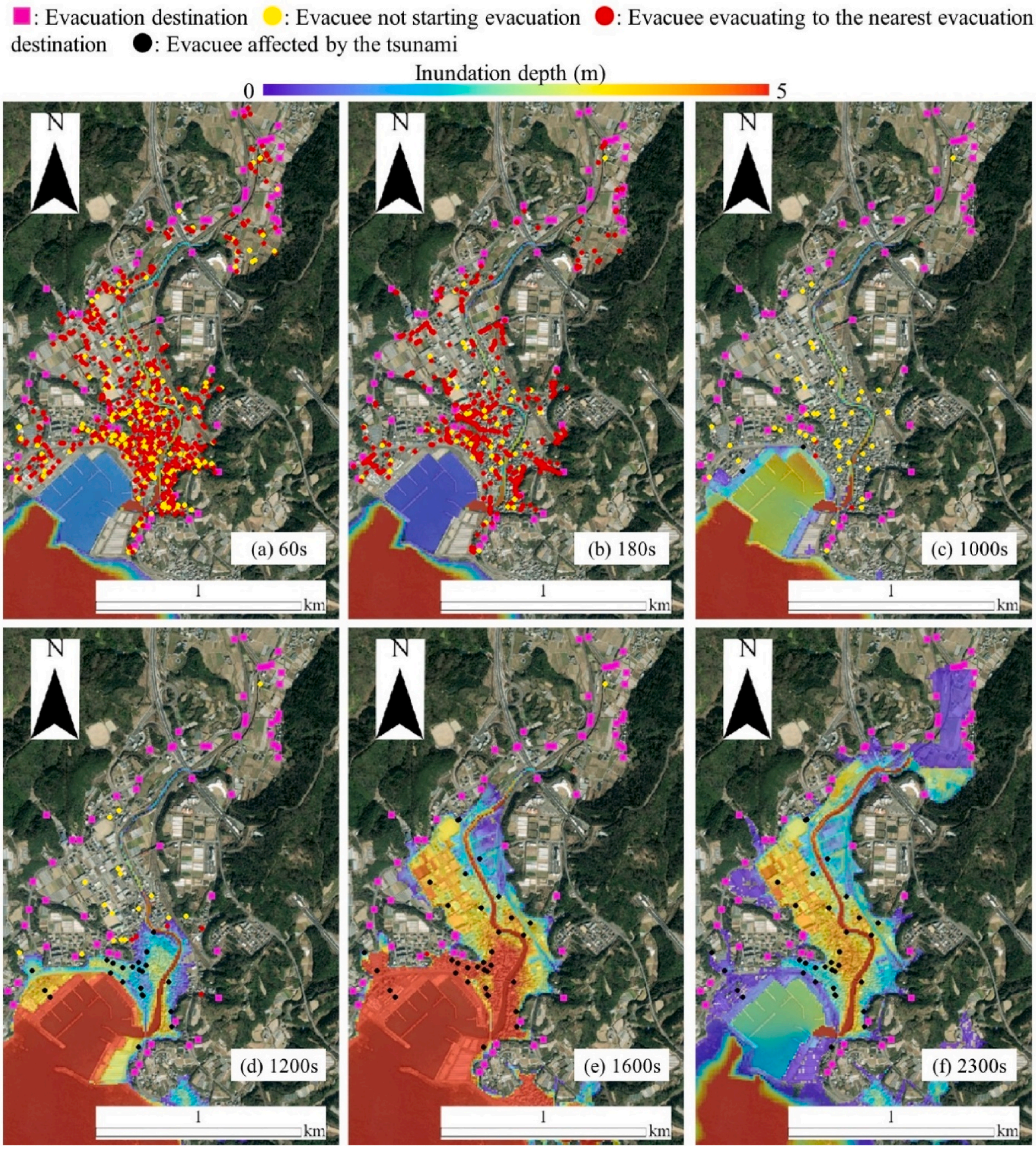

Fig. 5. Snapshots from the second simulation case at (a) 60 s, (b) 180 s, (c) 1000 s, (d) 1200 s, (e) 1600 s, and (f) 2300 s following the occurrence of the earthquake.

These results underscore the importance of modelling evacuation behaviour at a more granular level, such as the district level, and considering route choices and road conditions, as these factors significantly influenced both the simulated outcomes and the estimated number of affected people.

Overall, the simulated results confirmed that the outcomes of ABM tsunami evacuation simulations are heavily influenced by the assumptions embedded within the model. Therefore, enhancing these assumptions through collaboration with residents of the study area was highlighted to be crucial.

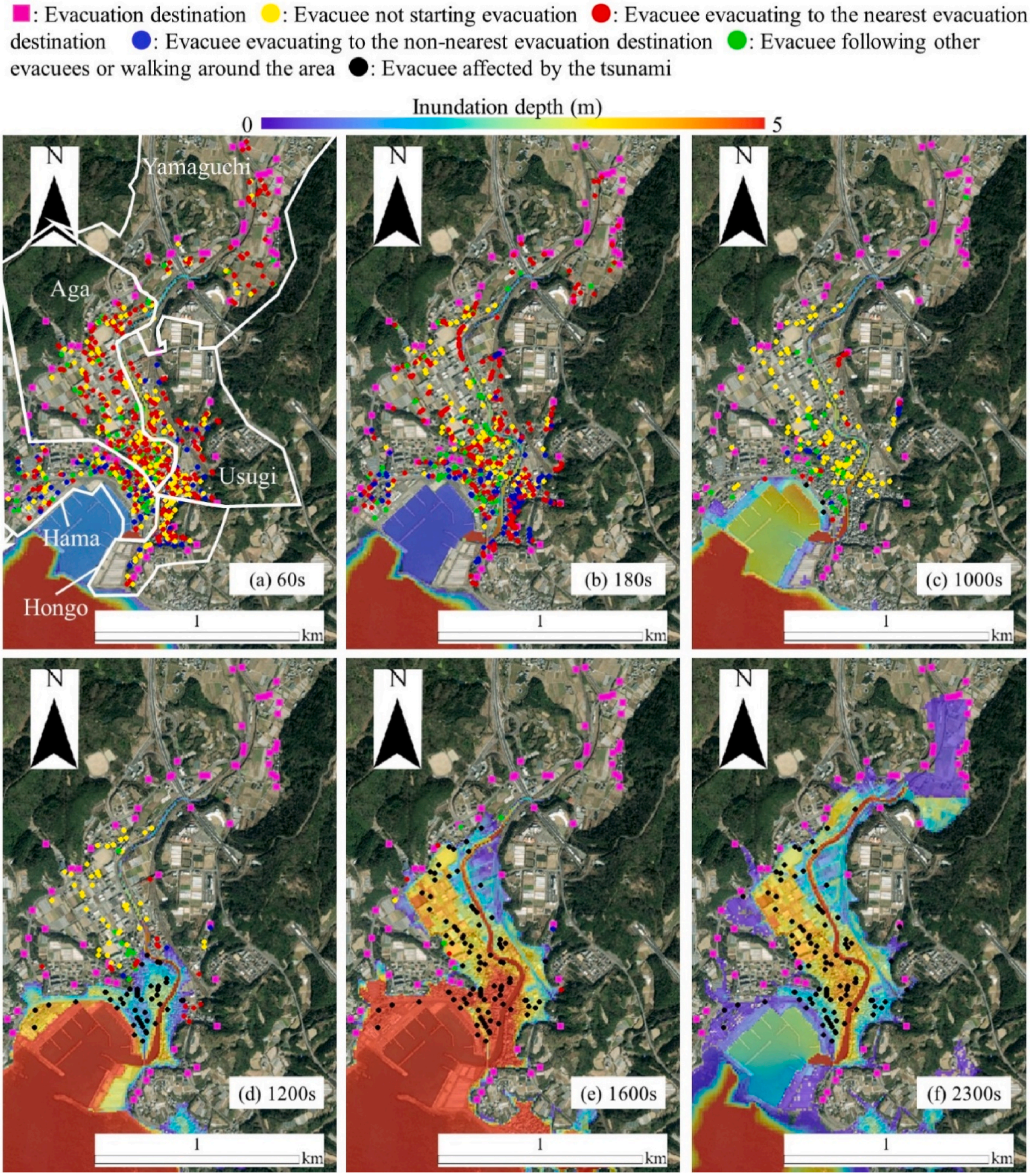

Fig. 6. Snapshots from the third simulation case at (a) 60 s, (b) 180 s, (c) 1000 s, (d) 1200 s, (e) 1600 s, and (f) 2300 s following the occurrence of the earthquake. White colored lines in Fig. 4(a) delineate the local districts within the study area.

3.2. Part 2 workshops

3.2.1. Participants

As stated in the earlier, the research team conducted a total of three workshops in Inami town with school children aged 11 and 12. These workshops focused on disaster education, ABM and general engagement. Two of these were conducted in November 2023 and one was conducted in January 2024. In total, 33 school pupils took part in the three workshops – which were mostly delivered in Japanese, though there were some English parts (delivered at a standard deemed suitable for the pupils). No demographic data about the pupils was collected other than their age during the workshops.

3.2.2. Workshop content

Key parameters were presented to the children in the first workshop. These were the assumptions that are made when producing an initial ABM for a given area – 2 evacuees per building, evacuation begins 15 min after the earthquake, movement is at a constant speed, and the shortest route is taken to the closest evacuation destination. These assumptions present an idealised version of flood evacuation in the area and allow for the creation of an ABM that does not hold actual figures about speed or the decisions taken during evacuation – it serves as a simpler mock up to help visualise what an ABM looks like. Such assumptions are a means to standardise These parameters were used to facilitate discussions about personal flood evacuation, with reflections about how the children would feel, behave, and react to their circumstances if the need for flood evacuation arose. These discussions sought to foster understanding about flood evacuation and its causal factors. The secondary workshop sought to illustrate the differences visible within an enhanced model where social data (e.g. specific evacuation times of residents) was incorporated with the ABM through the comparisons discussions were facilitated and children expressed differences and similarities that they could see. The final workshop sought to understand how the children felt about the workshops, their overall understanding and feeling to the experience, this was followed by an evaluation survey that sought to gauge this elements.

3.2.3. Location – Children's districts in Inami Town

We also asked about pupil's behaviour during the annual tsunami training to get a sense of where pupils were located.

3.2.4. Data collection & analysis

As mentioned above, following the three workshop sessions, pupils were asked to fill out a survey – questions and answers were in Japanese (n = 33). Tables 3–6 reflect data drawn from the survey.

This survey was split into three parts, asking pupils.

a) about their perceptions around the workshops (e.g., engagement, delivery);
b) their perceptions around ABM (e.g., perceived understanding); and
c) more general questions around their learnings.

3.2.4.1. Part A. Pupils were typically (unless otherwise stated) asked to respond using a 1–5 Likert scale in order of strength of agreement with the statement. For example, "Were the three lessons easy to understand?" e.g., 1 = It wasn't easy to understand at all, 2 It wasn't very easy to understand, 3 = Neither agree nor disagree, 4 = It was somewhat easy to understand, 5 = It was very easy to understand. There were also some qualitative open text responses, where pupils were given the opportunity to elaborate more about their experience.

Pupils were asked about their intentions on evacuation during a drill. On a Sunday afternoon in early November at around 5:00 p.m., you felt a strong, long ground shaking with an intensity of about 6 on the Japanese seismic scale at your home. Would you evacuate at that time? Most students responded that they would evacuate; I will evacuate (n = 22, 66.7 %), I will not evacuate (n = 2, 6.1 %), I do not need to evacuate (n = 9, 27.3 %)

Students were then asked when they would start to evacuate: To those who chose to evacuate, at what point do you start your evacuation? Responses were: After ground shaking stops (n = 16, 48.5 %), After hearing a tsunami warning (n = 7, 21.2 %)

Pupils were also asked a binary question where they would evacuate to – whether it would be the nearest evacuation site or not. To those who chose to evacuate, where are you going to evacuate? Nearest evacuation site (n = 22, 66.7 %), Not the nearest evacuation site (n = 2, 6.1 %)

Pupils were asked about their intentions to evacuate following the ABM session. After viewing the results of the ABM simulation, how have your thoughts changed? Based on the simulation results, please answer the same question again. Would you evacuate at that time? Responses: I will not evacuate (n = 1, 3 %), I do not need to evacuate (n = 6, 18.2 %), I will evacuate (n = 26, 78.8 %)

To those who chose to evacuate, at what point do you start your evacuation? After ground shaking stops (n = 23, 69.7 %), After hearing a tsunami warning (n = 3, 9.1 %)

Table 3
Mean responses (1–5) to **pupil's perceptions of the workshops**.

	Mean (*Standard Deviation*)
Were the three lessons easy to understand?	4.82 (.39)
How engaging do you think the university visitors have made the topic?	4.85 (.36)
How well organised were the sessions with the visitors?	4.72 (.76)
How do you feel the first session prepared you for the second and third sessions?	4.97 (.17)

Table 4
Pupil's perceptions of ABM simulation.

	Mean(*StandardDeviation*)
1st ABM simulation results. How well did you understand the results of the simulation?	4.64 (.70)
How realistic do you think the results of the simulation are? (1 = Not realistic at all to 5 = Very realistic)	3.67 (1.27)
2nd ABM simulation results. How well did you understand the results of the simulation?	4.79 (.42)
How realistic do you think the results of the simulation are?	4.36 (.55)
3rd ABM simulation results. How well did you understand the results of the simulation?	4.85 (.44)
How realistic do you think the results of the simulation are?	4.70 (.47)
Before learning about ABM and viewing the results of ABM, to what extent did you think a tsunami is to affect you in the future? (1 = Not at all likely to 5 = Almost certain)	3.94 (.97)
After learning about ABM and viewing the results of ABM, to what extent do you think a tsunami is to affect you in the future?	4.12 (1.17)
To what extent do you feel you made a contribution to university research? (1 = I don't feel my participation contributed to the research to 5 = I feel my participation in the sessions made a pick contribution)	4.18 (.58)
To what extent do you think your understanding of evacuations during a tsunami has increased following the information around ABM? (1 = Not very much to 5 = Very much)	4.91 (.29)

Table 5
Which part of the sessions the pupils you **learnt** the most.

	First		Second		Third	
	n	%	*n*	%	*n*	%
Basics of agent simulation	4	12.1	4	12.1	6	18.2
Agent simulation at Inami Town (first simulation)	2	6.1	3	9.1	2	6.1
Are the assumptions of the simulation appropriate? (Group discussion)	1	3.0	9	27.3	2	6.1
Homework (Survey)	1	3.0	1	3.0	7	21.2
Disaster events in Japan and the UK	1	3.0	2	6.1	7	21.2
Agent simulation that partially reflects the results of the homework (2nd simulation)			4	12.1	1	3.0
Let's understand the characteristics of agent simulation (experiment in a gymnasium)	2	6.1	5	15.2	4	12.1
Simulation besides evacuation	1	3.0	4	12.1	1	3.0
Agent simulation that reflects all homework results (3rd simulation)	21	63.6	1	3.0	3	9.1

Table 6
Which part of the sessions the pupils **enjoyed** the most.

	First		Second		Third	
	n	%	*n*	%	*n*	%
Basics of agent simulation	1	3.0	1	3.0	2	6.1
Agent simulation at Inami Town (first simulation)	1	3.0	1	3.0	1	3.0
Are the assumptions of the simulation appropriate? (Group discussion)	9	27.3	5	15.2	4	12.1
Homework (Survey)	1	3.0	3	9.1	3	9.1
Disaster events in Japan and the UK	3	9.1	6	18.2	11	33.3
Agent simulation that partially reflects the results of the homework (2nd simulation)			2	6.1		
Let's understand the characteristics of agent simulation (experiment in a gymnasium)	13	39.4	9	27.3	2	6.1
Simulation besides evacuation			2	6.1	5	15.2
Agent simulation that reflects all homework results (3rd simulation)	5	15.2	4	12.1	5	15.2

3.2.4.2. Part B. Pupils were also asked about the ABM sessions. The results are as follows.

After learning about ABM and viewing the results of ABM, have you thought about the necessity to improve your own evacuation behaviour? No ($n = 9$, 27.3 %), Yes ($n = 24$, 72.7 %)

3.2.4.3. Part C. Overall, the pupils felt their (and the other residents') input is very important: How important do you think students' and residents' inputs are for DRR in the town (1 = Not very important to 5 = Very important). Mean = 5, SD = .00.

4. Discussion

4.1. ABM & effective flood evacuation

This research has illustrated that ABM allows for direct engagement and inclusion of context specific factors that may play an influencing role in the evacuation efficacy of residents during worst case flooding scenarios. This is notable as current practice only accounts for limited context specific variables (the area's topography and very basic demographics) [8], so there is little insight into the circumstances and characteristics of the resident population. Yet, across the disaster research spectrum, there is considerable evidence of the influencing role of social factors in determining behaviour during emergencies (Sadri, Ukkusuri and Ahmed, 2021), so it is logical to engage with such factors to understand how they can be addressed – this provides an access point to directly improving flood evacuation efficacy. Drawing on the results, it is evident that when the modelling included information about the precise evacuation start time, this variable notably increased the precision in understanding evacuation behaviour, which could give insight where evacuation start times are inadequate and present an incentive for change.

Beyond this, ABM also offers a cost-effective mode of testing different flood evacuation interventions that enables experimentation and review of the adequacy of pre-existing practices. As seen with the enhanced model, which only accounts for the inclusion of one social variable (the evacuation start time), there is already considerable insight gained, in that there is a great degree of difference between the initial and enhanced model – with 'agents' moving via alternative times/routes. This means that addition of the variable had an impact on the evacuation behaviour. As this was a pilot study, the first step in comparing these models was to identify if the social data inclusion elicited a notable change and the use of evacuation start time did this, which mandates further review of other variables. If alternative additions are made, then there is a potential that other effects will be witnessed and new insights gained, which is useful considering the growing pressure and limited time in enacting progress across the DRR field due to rising risks resulting from climate change [53]. Based on this, it is necessary to continue such modelling, whilst including further social variables.

4.2. PAR & early education

PAR seeks to provide an opportunity to have a direct involvement in the research process [41], and in this case, this was accomplished through the homework and workshops – the children had direct opportunities to offer input and shape reflections. Overall, the workshops were perceived positively with all indicators illustrating an increase in DRR engagement – with specific positive view of the group activities and workshop finale (including the enhanced model presentation). Following the administration of the evaluation survey, it became clear that across the workshops, students felt that they learnt from the experience of participating in this research project – particularly its component elements of ABM and flood evacuation. This is important in part for the reason outlined earlier, that early education/learning plays an important role in fostering DRR engagement in the present as well as for the future ([10]; Luetz and Sultana, 2019; [39]), but also because it may support evacuation efficacy of the children in the present, which could increase their safety if severe flooding occurred. Despite this, it is not possible to know this for certain as validation would require an extreme hazard event, which is uncontrollable and the desire for its presence as a mode of validation is unethical.

In terms of the learning that students expressed having experienced, this can be attributed to several components of the research. Firstly, as this study was intertwined within the school curriculum it may have been easier for students to draw parallels between their schoolwork and the research focus [54], and as such, these parallels may have facilitated learning through drawing similarities between these two elements. Secondly, as the homework component of the research meant that the students had to ask questions themselves rather than the research team doing so, this could have encouraged them to reflect and build their understanding. As the level of understanding increased across the workshops, it would suggest that the homework activity played a role in supporting this development. However, it would be beneficial to monitor this more closely to identify precisely at what point in the workshops the students learned the most and why this might be the case. Aside from this, the final key point to note is the role played by the discussions that occurred within the workshops, particularly where students exchanged views that were similar as well as those that challenged their peers. Such interactions were potential opportunities for useful reflection and idea development [55], where students constructed their views towards their own evacuation behaviour. In synthesis, while this research involved explaining concepts to students and presenting information about ABM/flood evacuation, the students themselves constructed their knowledge and views, and we directly involved in shaping project outcomes, which ultimately benefited their DRR knowledge and skills.

4.3. Local engagement & DRR awareness

This research serves as evidence of the potential that ABM has in supporting the framing of DRR action in ways that are easy to view. Due to being a highly visual tool – generating a live map that shows evacuees moving – ABM helps create a sense of clarity in terms of what is happening. This is supported by the high level of understanding expressed by pupils, and the growth in understanding across each workshop. This growth in particular is important because it showcases the need for local engagement to be a continuous, repeat process rather than a single, one-time activity, which is supports findings from prior research [9]. Despite this, in terms of pupils' understanding, using a Likert scale to measure this is limited because this reflects the idea of understanding in the broader view (Jebb, Ng and Tay, 2021), rather than directly engaging with this position of understanding through asking deeper questions and reflecting on pupils responses – such interaction would not only serve to validate findings further, but also offer more meaningful, direct insights indicating which specific elements of the engagement activities that were especially salient. Moreover, through the agency of children in this project, the wider Inami community was engaged with as the homework required the children to seek out responses about flood evacuation from those around them – residents of Inami town. This wider engagement served to elicit reflection from community members, encouraging them to think about how they would behave in such situations, which is a vital part of DRR awareness – reflecting on behaviour in emergencies.

5. Conclusions

This study focused on illustrating how flood evacuation can be enhanced and how children can be better engaged in DRR actions like flood evacuation through the unison of PAR and ABM in the context of DRR. When comparing the modelling across the 3 models in the results section, it is evident that a greater inclusion of social variables yields a more accurate and realistic simulation of likely behaviour during flood evacuation in the specific context of Inami town. This is important because it confirms the presumed position that current approaches used by councils in preparing for potential natural hazards (their evacuation plans) are not optimal, and that there is potential for enhancement. Despite this, it is important to note that the sample size of this study is limited and 66 individuals cannot sufficiently reflect the evacuation behaviour of the entire population of Inami town. However, as this is a pilot study, such a reality (of limited representativeness) is expected and does not dilute the points that these outputs express – they are mere suggestions of a potential reality that need to be retested under stricter conditions to further validate these findings.

There are several limitations faced by the present study that are relevant to consider as a means for improving any future research seeking to build on these findings. Firstly, it is pivotal to acknowledge that despite this research taking place in Inami town, Japan, there is a need to investigate many other Japanese flood-prone communities to understand whether the enhancements in modelling evacuation behaviour found in this research would also be apparent in other areas across the country (homogeneity should not be assumed). Even more broadly, there is a necessity to conduct similar studies across the world to gauge the replicability of these findings and to check the viability of adapting this research to dissimilar localities, where more complex parameters may need to be considered – this might be especially useful in outlining the limits of this type of modelling.

Beyond the above, a second key point to consider is the reality that embedding certain variables within the ABM is more challenging than others, and this poses restrictions on the inclusivity of the ABM, which ultimately limits its potential. For example, engaging with variables like evacuation start time is relatively simple as this simply dictates when an agent begins to move from their assigned home to the evacuation site within the simulation. In contrast, the effect of age or disability on the speed of the agent are more difficult to consider as this exists on a different numerical spectrum and raises questions about how to most accurately reflect this within the simulation – using the mean or some formula, though this would need to be heavily supported with evidence to its use. In synthesis, while these limitations are important to improving the research and need to be considered, they do not invalidate the findings. And it should be acknowledged that these limitations were expected and are an essential part of any pilot research.

Crucially, this pilot study demonstrates promising results, outlining that with the inclusion of social datasets in ABM, in the context of flood evacuation/DRR, a more accurate picture of flood evacuation within a certain area can be created. And such output has meaningful implications, particularly in influencing how evacuation can be improved – whether through reassessment of evacuation routes, changing the locations of evacuation sites or through other social interventions that address challenges identified in the models. Moreover, this study outlined that use of ABM facilitates engagement and awareness building amongst children, which is also an important finding as it reinforces the need to establish more impactful ways of involving all types of stakeholders in DRR action, to build greater disaster resilience. Based on this, it is evident that a larger study with consideration of more social variables to yield further insights about human behaviour during flood evacuation is mandated.

CRediT authorship contribution statement

Maciej Pawlik: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Tomoyuki Takabatake:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hideyuki Shiroshita:** Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Ravindra Jayaratne:** Writing – original draft, Visualization, Supervision, Resources, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization. **Hebba Haddad:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Kaori Kitagawa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nanami Hasegawa:** Visualization, Software, Resources, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

[1] Environment Agency, Coastal change pathfinder review report, Available at: https://www.gov.uk/government/publications/coastal-change-management/defra-coastal-change-pathfinder-review-report, 2021. (Accessed 28 July 2024) (Accessed.
[2] J.T. Roberts, Global inequality and climate change, Soc. Nat. Resour. 14 (6) (2010) 501–509.
[3] Climate Action Tracker, CAT emissions gap. https://climateactiontracker.org/global/cat-emissions-gaps/, 2024. (Accessed 20 August 2024).
[4] J. Fan, G. Huang, Evaluation of flood risk management in Japan through a recent case, Sustainability 12 (13) (2020) 5357.
[5] L. Kuhl, P.H. Krishen, M. Ruth, E.M. Douglas, Evacuation as a climate adaptation strategy for environmental justice communities, Clim. Change 127 (2014) 493–504.
[6] J. McLennan, K. Reid, R. Beilin, Shared responsibility, community engagement and resilience: international perspectives, Aust. J. Emerg. Manag. 34 (3) (2019) 40–46.
[7] F.E. Kwabena, Flood hazard mapping using aster image data with GIS, Int. J. Geomatics Geosci. 1 (4) (2011) 932–950.
[8] R.J. Dawson, R. Peppe, M. Wang, An agent-based model for risk-based flood incident management, Nat. Hazards 59 (2011) 167–189, https://doi.org/10.1007/s11069-011-9745-4.
[9] M. Pawlik, K. Kitagawa, H. Shiroshita, R. Jayaratne, S. Nomoto, Y. Okumura, K. Kono, Proposing thematic mapping for integrated risk communication: a study of British & Japanese perspectives in flood-prone communities, Int. J. Disaster Risk Reduc. 107 (2024) 104472.
[10] N.H. Rofiah, N. Kawai, E.N. Hayati, Key elements of disaster mitigation education in inclusive school setting in the Indonesian context, Jàmbá: Journal of Disaster Risk Studies 13 (2021) 1–8.
[11] J. Pollard, T. Spencer, S. Brooks, The interactive relationship between coastal erosion and flood risk, Prog. Phys. Geogr. Earth Environ. 43 (4) (2019) 574–585.
[12] J.D. Woodruff, J.L. Irish, S.J. Camargo, Coastal flooding by tropical cyclones and sea-level rise, Nature 504 (2013) 44–52.
[13] S. Dong, S. Abolfathi, M. Salauddin, Z. Tan, J. Pearson, Enhancing climate resilience of vertical seawall with retrofitting - a physical modelling study, Appl. Ocean Res. 103 (2020) 102331.
[14] R.L. Morris, T.M. Konlechner, M. Ghisalberti, S.E. Swearer, From grey to green: efficacy of eco-engineering solutions for nature-based coastal defence, Global Change Biol. 24 (4) (2018) 1827–1842.
[15] T. Takabatake, M. Esteban, T. Shibayama, Simulated effectiveness of coastal forests on reduction in loss of lives from a tsunami, Int. J. Disaster Risk Reduc. 74 (2022) 102954.
[16] G.M. Martins, A.F.S. Amaral, F. Wallenstein, A. Neto, Influence of a breakwater on nearby rocky intertidal community structure, Mar. Environ. Res. 67 (4–5) (2009) 237–245.
[17] T. Dolphin, C. Vincent, J. Bacon, E. Dumont, A. Terentjeva, Decadal-scale impacts of a segmented, shore-parallel breakwater system, Coastal Engineering 66 (2012) 24–34.
[18] X. Pan, C. Han, K. Dauber, K. Law, A multi-agent based Framework for the simulation of human and social behavior during emergency evacuations, AI Soc. 22 (2) (2007) 113–132, https://doi.org/10.1007/s00146-007-0126-1.
[19] Z. Liu, C.C. Jacques, S. Szyniszewski, J.K. Guest, B.W. Schafer, et al., Agent-based simulation of building evacuation after an earthquake: coupling human behavior with structural response, Nat. Hazards Rev. 17 (1) (2015) 1–14, https://doi.org/10.1061/(ASCE)NH.1527-6996.0000199.
[20] G. Coates, C. Li, S. Ahilan, N. Wright, M. Alharbi, Agent-based modeling and simulation to assess flood preparedness and recovery of manufacturing small and medium-sized enterprises, Eng. Appl. Artif. Intell. 78 (2019) 195–217, https://doi.org/10.1016/j.engappai.2018.11.010.
[21] J. Simmonds, J.A. Gómez, A. Ledezma, The role of agent-based modeling and multi-agent systems in flood-based hydrological problems: a brief review, Journal of Water and Climate Change 11 (2020) 1580–1602.
[22] E. Mas, S. Koshimura, F. Imamura, A. Suppasri, A. Muhari, et al., Recent advances in agent-based tsunami evacuation simulations: case studies in Indonesia, Thailand, Japan and Peru, Pure Appl. Geophys. 172 (2015) 3409–3424, https://doi.org/10.1007/s00024-015-1105-y.
[23] H. Wang, A. Mostafizi, L.A. Cramer, D. Cox, H. Park, An agent-based model of a multimodal near-field tsunami evacuation: decision-making and life safety, Transport. Res. Part C Emerg. Technol. 64 (2016) 86–100, https://doi.org/10.1016/j.trc.2015.11.010.
[24] T. Takabatake, T. Shibayama, M. Esteban, H. Ishii, G. Hamano, Simulated tsunami evacuation behavior of local residents and visitors in kamakura, Japan, Int. J. Disaster Risk Reduct. 23 (2017) 1–14, https://doi.org/10.1016/j.ijdrr.2017.04.003.
[25] Y. Uno, Y. Shigihara, A. Okayasu, Development of crowd evacuation simulation for risk evaluation of human damage by tsunami inundation, Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering) 71 (2) (2015) 1615–1620, https://doi.org/10.2208/kaigan.71.I_1615.
[26] T. Takabatake, M. Esteban, I. Nistor, T. Shibayama, S. Nishizaki, Effectiveness of hard and soft tsunami countermeasures on loss of life under different population scenarios, Int. J. Disaster Risk Reduct. 45 (2020) 101491, https://doi.org/10.1016/j.ijdrr.2020.101491.
[27] W.M. Johnstone, B.J. Lence, Assessing the value of mitigation strategies in reducing the impacts of rapid-onset, catastrophic floods, J. Flood Risk Manag. 2 (3) (2009) 209–221, https://doi.org/10.1111/j.1753-318X.2009.01035.x.
[28] W.M. Johnstone, B.J. Lence, Use of flood, loss, and evacuation models to assess exposure and improve a community tsunami response plan: vancouver island, Nat. Hazards Rev. 13 (2) (2012) 162–171, https://doi.org/10.1061/(ASCE)NH.1527-6996.0000056.
[29] Y. Koyanagi, T. Arikawa, Study of the tsunami evacuation tower using the tsunami evacuation simulation, Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering) 72 (2) (2016) 1567–1572, https://doi.org/10.2208/kaigan.72.I_1567.
[30] A. Mostafizi, H. Wang, D. Cox, S. Dong, An agent-based vertical evacuation model for a near-field tsunami: choice behavior, logical shelter locations, and life safety, Int. J. Disaster Risk Reduct. 34 (3) (2019) 467–479, https://doi.org/10.1016/j.ijdrr.2018.12.018.
[31] T. Takabatake, K. Fujisawa, M. Esteban, T. Shibayama, Simulated effectiveness of a car evacuation from a tsunami, Int. J. Disaster Risk Reduct. 47 (2020) 101532, https://doi.org/10.1016/j.ijdrr.2020.101532.
[32] Z. Wang, G. Jia, Simulation-based and risk-informed assessment of the effectiveness of tsunami evacuation routes using agent- based modeling: a case study of seaside, Oregon, Int. J. Disaster Risk Sci. 13 (2022) 66–86, https://doi.org/10.1007/s13753-021-00387-x.
[33] K. Kumagai, Validation of tsunami evacuation simulation to evacuation activity from the 2011 off the pacific coast of Tohoku earthquake tsunami, Journal of Japan Society of Civil Engineers, Ser. D3 (Infrastructure Planning and Management) 70 (5) (2014) 187–196, https://doi.org/10.2208/jscejipm.70.I_187.
[34] E. Ito, H. Kawase, S. Matsushima, M. Hatayama, Tsunami evacuation simulation considering road blockage by collapsed buildings evaluated from predicted strong ground motion, Nat. Hazards 101 (2020) 959–980, https://doi.org/10.1007/s11069-020-03903-2.
[35] T. Takabatake, D.H. Chenxi, M. Esteban, T. Shibayama, Influence of road blockage on tsunami evacuation: a comparative study of three different coastal cities in Japan, Int. J. Disaster Risk Reduct. 68 (2022) 102684, https://doi.org/10.1016/j.ijdrr.2021.102684.
[36] T. Takabatake, T. Shibayama, M. Esteban, H. Ishii, Advanced casualty estimation based on tsunami evacuation intended behavior: case study at yuigahama beach, kamakura, Japan, Nat. Hazards 92 (3) (2018) 1763–1788, https://doi.org/10.1007/s11069-018-3277-0.
[37] J. Becker, H. Taylor, B.J. Doody, K. Wright, E. Gruntfest, D. Webber, A review of people's behaviour in and around floodwater, Weather, Climate, and Society 7 (4) (2015) 321–332.
[38] S. Laska, B.H. Morrow, Social vulnerabilities and hurricane katrina: an unnatural disaster in new orleans, Mar. Technol. Soc. J. 40 (4) (2006) 16–26.
[39] D.I. Prambudi, Integrating disaster mitigation education in the elementary school curriculum. Presented at the 1st International Conference on Social Sciences Education - "Multicultural Transformation in Education, Social Sciences and Wetland Environment" (ICSSE 2017), Atlantis Press, 2017, pp. 79–82.
[40] L. Jerome, H. Starkey, Children's Rights Education in Diverse Classrooms: Pedagogy, Principles, Practice, Bloomsbury Publishing, 2021.
[41] K. Kitagawa, Researcher positionality in participatory action research for climate justice in indigenous communities, Int. J. Qual. Methods 22 (2023).
[42] P. Freire, Pedagogy of the Oppressed, Translated by Ramos, Myra Bergman, New York, 1971. Herder and Herder.
[43] O. Fals-Borda, The North-South convergence: a 30-year first-person assessment of PAR, Action Res. 4 (3) (2006) 351–358.
[44] M. Walker, A. Boni, Participatory Research, Capabilities and Epistemic Justice: A Transformative Agenda for Higher Education, Springer International Publishing AG, Cham, 2020. Cham.

[45] A. Boni, A.A. Frediani, Expanding capabilities through participatory action research, in: E.C. Martinetti, S. Osmani, M. Qizilbash (Eds.), The Cambridge Handbook of the Capability Approach, Cambridge University Press, Cambridge, 2020.
[46] N.J. Godden, P. Macnish, T. Chakma, K. Naidu, Feminist participatory action research as a tool for climate justice, Gend. Dev. 28 (3) (2020) 593–615.
[47] F. Baum, C. MacDougall, D. Smith, Participatory action research, J. Epidemiol. Community Health 60 (10) (2006) 854–857.
[48] G. Charnes, Briefing Paper 2: Setting up of Participatory Action Reflection Learning (PARL) Group - the Chilean Experience, 2014.
[49] K. Kitagawa, Conceptualising "disaster education", Special Issue Advances in education and training for disaster risk reduction and management. Education Sciences 11 (2021) 233–248.
[50] K. Kitagawa, Disaster risk reduction activities as learning, Nat. Hazards 105 (2020) 3099–3118.
[51] K. Koyano, T. Takabatake, M. Esteban, T. Shibayama, Influence of edge waves on tsunami characteristics along Kujukuri beach, Japan, J. Waterw. Port, Coast. Ocean Eng. 147 (2021) 04020049, https://doi.org/10.1061/(ASCE)WW.1943-5460.0000617.
[52] Cabinet Office of Japan, 'Guidelines for Tsunami Evacuation Buildings' 104p, 2005 (in Japanese).
[53] N.W. Arnell, S.N. Gosling, The impacts of climate change on river flood risk at the global scale, Clim. Change 134 (2016) 387–401.
[54] J.W. Willison, When academics integrate research skill development in the curriculum, High Educ. Res. Dev. 31 (6) (2012) 905–919.
[55] B. Rogoff, Developing understanding of the idea of communities of learners, Mind Cult. Activ. 1 (4) (2009) 209–229.